Rec'd PCT/PTO 26 APR 2001

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U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

# TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

ATTORNEY'S DOCKET NUMBER
**206094US2PCT**

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR
09/807959

| INTERNATIONAL APPLICATION NO. | INTERNATIONAL FILING DATE | PRIORITY DATE CLAIMED |
|---|---|---|
| **PCT/JP00/05704** | **24 August 2000** | **27 August 1999** |

TITLE OF INVENTION
**METHOD OF GENERATING A SYNCHRONISATION PULSE AND METHOD OF RECEIVING AN OFDM SIGNAL**

APPLICANT(S) FOR DO/EO/US
**Stephen K. BARTON, et al.**

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☐ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
   - a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
   - b. ☒ has been transmitted by the International Bureau.
   - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☒ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ A copy of the International Search Report (PCT/ISA/210).
8. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
   - a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
   - b. ☐ have been transmitted by the International Bureau.
   - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   - d. ☒ have not been made and will not be made.
9. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
10. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
11. ☐ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).

**Items 13 to 20 below concern document(s) or information included:**

13. ☐ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☒ A **FIRST** preliminary amendment.
16. ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
17. ☐ A substitute specification.
18. ☐ A change of power of attorney and/or address letter.
19. ☐ Certificate of Mailing by Express Mail
20. ☒ Other items or information:

**Request for Consideration of Documents Cited in International Search Report**
**Notice of Priority**
**Drawings (6 Sheets)**



PCTUS1/REV03

JC08 Rec'd PCT/PTO 26 APR 2001

| U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR | INTERNATIONAL APPLICATION NO. | ATTORNEY'S DOCKET NUMBER |
|---|---|---|
| 09/807959 | PCT/JP00/05704 | 206094US2PCT |

21. The following fees are submitted:.

**BASIC NATIONAL FEE ( 37 CFR 1.492 (a) (1) - (5)) :**

| | CALCULATIONS | PTO USE ONLY |
|---|---|---|
| ☐ Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2) paid to USPTO and International Search Report not prepared by the EPO or JPO ............ **$1,000.00** | | |
| ☒ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but Internation Search Report prepared by the EPO or JPO .......... **$860.00** | | |
| ☐ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO ............ **$710.00** | | |
| ☐ International preliminary examination fee paid to USPTO (37 CFR 1.482) but all claims did not satisfy provisions of PCT Article 33(1)-(4) ............ **$690.00** | | |
| ☐ International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(1)-(4) .......... **$100.00** | | |
| **ENTER APPROPRIATE BASIC FEE AMOUNT =** | **$860.00** | |
| Surcharge of **$130.00** for furnishing the oath or declaration later than ☒ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (e)). | **$130.00** | |

| CLAIMS | NUMBER FILED | NUMBER EXTRA | RATE | | |
|---|---|---|---|---|---|
| Total claims | 23 - 20 = | 3 | x $18.00 | **$54.00** | |
| Independent claims | 5 - 3 = | 2 | x $80.00 | **$160.00** | |
| Multiple Dependent Claims **(check if applicable).** | | | ☐ | **$0.00** | |
| **TOTAL OF ABOVE CALCULATIONS** | | | = | **$1,204.00** | |
| Reduction of 1/2 for filing by small entity, if applicable. Verified Small Entity Statement must also be filed (Note 37 CFR 1.9, 1.27, 1.28) **(check if applicable).** | | | ☐ | **$0.00** | |
| **SUBTOTAL** | | | = | **$1,204.00** | |
| Processing fee of **$130.00** for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (f)). | | | + | **$0.00** | |
| **TOTAL NATIONAL FEE** | | | = | **$1,204.00** | |
| Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) **(check if applicable).** | | | ☐ | **$0.00** | |
| **TOTAL FEES ENCLOSED** | | | = | **$1,204.00** | |
| | | | | **Amount to be: refunded** | $ |
| | | | | **charged** | $ |

☒ A check in the amount of **$1,204.00** to cover the above fees is enclosed.

☐ Please charge my Deposit Account No. in the amount of to cover the above fees. A duplicate copy of this sheet is enclosed.

☒ The Commissioner is hereby authorized to charge any fees which may be required, or credit any overpayment to Deposit Account No. **15-0030** A duplicate copy of this sheet is enclosed.

**NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.**

SEND ALL CORRESPONDENCE TO:

**22850**

Surinder Sachar
Registration No. 34,423

Surinder Sachar

SIGNATURE

**Marvin J. Spivak**

NAME

**24,913**

REGISTRATION NUMBER

April 26 2001

DATE

206094US

IN THE UNITED STATES PATENT & TRADEMARK OFFICE

IN RE APPLICATION OF :

STEPHEN K. BARTON ET AL : ATTN: APPLICATION DIVISION

SERIAL NO: NEW U.S. PCT APPLICATION :
(Based on PCT/JP00/05704)

FILED: HEREWITH :

FOR: METHOD OF GENERATING A SYNCHRONISATION PULSE AND METHOD OF RECEIVING AN OFDM SIGNAL :



PRELIMINARY AMENDMENT

ASSISTANT COMMISSIONER FOR PATENTS
WASHINGTON, D.C. 20231

SIR:

Prior to a first examination on the merits, please amend the above-identified application as follows:

IN THE CLAIMS

Please amend the claims as follows:

5. (Amended) A method as claimed in claim 1, in which the signal representing the degree of correlation is subject to filtering prior to using the signal to determine said sub-interval, the filtering being such that each filtered output sample represents, substantially, an average of a predetermined number of successive samples, said predetermined number being substantially less than the number of samples within a guard space.

8. (Amended) A method as claimed in claim 5, wherein the filtered output is subjected to further filtering before being processed to provide a signal representing a fine frequency offset.

9. (Amended) A method as claimed in claim 1, including the step of adjusting the timing of the synchronisation pulse only if a calculated error in the current timing exceeds a predetermined threshold.

10. (Amended) A method as claimed in claim 1, including the step of adjusting the timing of the synchronisation pulse only if the current timing is determined to be in error over a predetermined number of symbol periods, the predetermined number of symbol periods being greater than one.

11. (Amended) A method as claimed in claim 1, wherein the timing of the synchronisation pulse is adjusted in predetermined quantities corresponding to a plurality of sample periods.

16. (Amended) A method as claimed in claim 12, wherein the timing of the synchronisation pulse is adjusted in predetermined quantities corresponding to a plurality of sample periods.

22. (Amended) Apparatus for generating a synchronising pulse, the apparatus operating according to a method as claimed in claim 1.

23. (Amended) An OFDM receiver arranged to operate in accordance with a method according to claim 17.

## REMARKS

Favorable consideration of this application, as presently amended, is respectfully requested.

The present Preliminary Amendment is submitted to place the above-identified application in more proper format under United States practice. By the present Preliminary Amendment the claims have been amended to no longer recite any multiple dependencies.

The present application is believed to be in condition for a full and thorough examination on the merits. An early and favorable consideration of the present application is hereby respectfully requested.

Respectfully submitted,

OBLON, SPIVAK, McCLELLAND,
MAIER & NEUSTADT, P.C.

Surinder Sachar

Gregory J. Maier
Attorney of Record
Registration No. 25,599
Surinder Sachar
Registration No. 34,423

22850

(703) 413-3000
Fax No.: (703) 413-2220
GJM:SNS\la
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**Marked-Up Copy**
Serial No: 206094US
Amendment Filed on:

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IN THE CLAIMS

Please amend the claims as follows:

--5. (Amended) A method as claimed in [any preceding] claim 1, in which the signal representing the degree of correlation is subject to filtering prior to using the signal to determine said sub-interval, the filtering being such that each filtered output sample represents, substantially, an average of a predetermined number of successive samples, said predetermined number being substantially less than the number of samples within a guard space.

8. (Amended) A method as claimed in claim 5, [6 or 7,] wherein the filtered output is subjected to further filtering before being processed to provide a signal representing a fine frequency offset.

9. (Amended) A method as claimed in [any preceding] claim 1, including the step of adjusting the timing of the synchronisation pulse only if a calculated error in the current timing exceeds a predetermined threshold.

10. (Amended) A method as claimed in [any preceding] claim 1, including the step of adjusting the timing of the synchronisation pulse only if the current timing is determined to be in error over a predetermined number of symbol periods, the predetermined number of symbol periods being greater than one.

11. (Amended) A method as claimed in [any preceding] claim 1, wherein the timing of the synchronisation pulse is adjusted in predetermined quantities corresponding to a plurality of sample periods.

16. (Amended) A method as claimed in [any one of claims] claim 12 [to 14], wherein the timing of the synchronisation pulse is adjusted in predetermined quantities corresponding to a plurality of sample periods.

22. (Amended) Apparatus for generating a synchronising pulse, the apparatus operating according to a method as claimed in [any one of claims] claim 1 [to 16].

23. (Amended) An OFDM receiver arranged to operate in accordance with a method according to [any one of claims] claim 17 [to 21].--

6/PRTS

SPECIFICATION



# METHOD OF GENERATING A SYNCHRONISATION PULSE AND METHOD OF RECEIVING AN OFDM SIGNAL

## TECHNICAL FIELD

This invention relates to OFDM modulation. It is particularly concerned with the generation of a synchronisation pulse representing an OFDM symbol boundary, for example for use in Fourier Transform demodulation.

## BACKGROUND ART

OFDM systems are well known. Various techniques have been used for synchronisation of OFDM receivers. Some of these techniques require transmission of a special synchronisation signal. Other techniques rely on a standard OFDM signal, in which a complete symbol comprises a "useful part" and a "guard space", the guard space sometimes being referred to as a guard interval, cyclic extension or cyclic prefix.

The guard space precedes the useful part of the symbol and contains a repeat of the data at the end of the useful part. (This is equivalent to having a guard space after the useful part, containing data which is the same as that at the beginning of the useful part.)

Synchronisation techniques which rely upon the duplicated data in the guard space generally operate by performing a cross correlation between complex samples spaced apart by the length of the useful part of the symbol. This generates a timing pulse which is used in Fourier Transformation of the received signal. The timing of the pulse is such that the Fourier Transform window contains only data from a single symbol.

If the timing is incorrect, inter-symbol-interference (ISI) occurs. However, the use of the guard space allows a certain amount of variation in the timing of the pulse while still avoiding ISI. The guard space should be longer than the longest expected spread of delays amongst signals received via different paths. The guard space is relatively small compared with the useful part of the signal; typically, the guard space may contain Nu/32, Nu/16, Nu/8 or Nu/4 samples, where Nu is the number of samples in the useful part of the symbol.

Various techniques exist for deriving the synchronisation pulse from the cross-correlation. Although these operate adequately in common reception conditions, there are circumstances in which the timing pulse is generated at an undesirable point, leading to ISI.

The cross-correlator, in the absence of noise or multi-path interference, produces an output which averages to zero except during the time that the guard space samples are cross correlated with the samples, in the useful part of the symbol, which are of equal value. During that period, the cross-correlator produces a high-level output. This high-level output terminates at the end of one symbol and the beginning of the next. One prior art arrangement integrates the output of the correlator, and then peak-detects the resultant signal to produce a timing pulse at the end of each symbol.

In the case of multi-path interference, wherein the same signal is received via different delays, in order to avoid ISI, the synchronisation pulse should be generated during a window which has a width equal to the overlap

between the guard spaces of the two received signals. However, the cross-correlator will produce a significant output throughout the period in which samples of either one or both of the guard space samples are being processed by the cross-correlator. In some circumstances, this will result in the timing pulse being provided outside the optimum window, thus resulting in ISI.

EP-A-0 772 332 describes other techniques for generating a synchronisation pulse. One such disclosed technique relies upon feeding the output of the correlator to a phase locked loop (PLL). This can also result in the synchronisation pulse being generated outside the optimum window in the case of significant noise or multi-path interference. Furthermore, a PLL requires a substantial number of symbol periods in order to achieve lock, which therefore results in substantial acquisition time.

A further problem which can arise in prior art arrangements results from the fact that, when the synchronisation pulse is adjusted as a result of, for example, changing signal conditions, the complex values in the frequency bins at the output of the FFT suffer varying degrees of phase rotation. Although a subsequent channel estimator and corrector can handle these changes, this can result in a further increase of acquisition time and requires a significant amount of processing power.

It would therefore be desirable to provide a technique for generating a synchronisation pulse in which these problems are avoided or at least mitigated.

## DISCLOSURE OF INVENTION

Aspects of the present invention are set out in the accompanying claims.

Namely, this invention is a method of generating a synchronisation pulse representing a symbol boundary in an OFDM signal comprising useful symbol periods separated by guard spaces, with data in each guard space corresponding to part of the data in a respective useful period, the method comprising a step of providing a signal representing the degree of correlation between samples of a received signal which are separated by a period corresponding to the useful part of the symbol, the signal thus providing an output representing for each symbol an interval during which significant correlation is found, and a step of determining a sub-interval within which a maximum degree of correlation occurs and arranging for the synchronisation pulse to be provided within this sub-interval.

According to a further aspect, a synchronisation pulse is generated by providing a signal representing the degree of correlation between samples of a received signal which are separated by a period corresponding to the useful part of the symbol, the signal thus providing an output representing an interval during which significant correlation is found, the method comprising the step of determining a sub-interval within which a maximum degree of correlation occurs, and arranging for the synchronisation pulse to be provided within this sub-interval.

In the case of multi-path interference, it is found that the degree of correlation is at a maximum throughout a period whose width corresponds to the overlap of the guard spaces. This is an optimum period for generation of the synchronisation pulse, because this will ensure that each Fourier Transform window contains samples from only one symbol, even though the

same symbol is received with different delays. Using the techniques of the present invention, the output of the cross-correlator is examined to determine when this optimum period occurs.

In a preferred embodiment, the output of the cross-correlator is compared with a threshold, and the optimum sub-interval defining the period in which the synchronisation pulse is to be generated is represented by the period during which the cross-correlator output exceeds this threshold. Preferably, the threshold is varied in dependence upon the output of the cross-correlator, and more preferably the threshold is based upon the maximum level of the correlator output.

The use of a threshold is regarded to be an independently inventive aspect of the invention. According to this further aspect, the output of a correlator which represents the degree of correlation between samples of a received signal which are separated by a predetermined number of sample intervals is applied to a level detector, and only those parts of the signal which exceed a predetermined (preferably variable) level are taken into account in determining the time at which a synchronisation pulse should be generated.

If desired, the timing pulse could be generated at any time during the window which represents maximum correlation, for example at the middle of this window. As the signal conditions vary, this point may shift, in which case the synchronisation pulse will alter accordingly. In the preferred embodiment, however, the timing of the synchronisation pulse is altered only if certain conditions are met. For example, the timing can be altered only if the current timing is found to be in error a predetermined number of times,

and/or only if the current error exceeds a predetermined amount. This technique, which is regarded to be an independently inventive aspect, avoids excessive numbers of changes in the timing of the Fourier Transform operation, each of which would cause a phase rotation of each of the carriers at the output of the FFT by a different angle, which would place a heavy workload on the channel estimator conventionally provided.

According to a still further aspect of the invention, there is provided at the output of the FFT means for imparting different phase rotations to the respective samples of the FFT output, this means being responsive to a signal representing the amount of shift imparted to a synchronisation pulse by a pulse generator for determining the amount of phase rotation applied. This allows very rapid, and indeed possibly instantaneous, compensation for changes in the timing of the synchronisation pulse. The phase rotations may be imparted by a circuit positioned between the FFT and the channel estimator and corrector, or alternatively the channel estimator and corrector can perform the phase rotation. Preferably, changes in the timing of the synchronisation pulse are arranged to occur relatively infrequently (according to the aspect of the invention mentioned previously), and preferably only, or normally, in predefined amounts. This facilitates the determination of the appropriate phase rotations to be applied to the FFT outputs. These phase rotations can be calculated in response to a signal representing an actual or prospective degree of shift in the timing of the synchronisation pulse, or alternatively could be derived from a look-up table addressed in accordance with such a signal.

In the prior art mentioned above, the output of the correlator is filtered, for example by using a sliding-window averager which sums the most recent

Ng samples from the cross-correlator. This filtering technique would, however, vary the shape of the correlator output, and accordingly, in the preferred embodiment of the present invention, the cross-correlator output is filtered by summing the most recent L1 samples, where L1 is significantly smaller than Ng.

It is known in the prior art to take the output of the sliding-window averager and process this to provide a signal used in fine frequency correction. This technique is preferably also used in arrangements according to the present invention. However, to obtain better quality of fine frequency estimation, in the preferred embodiment of the present invention, a second filter is applied to the output of the first filter, and produces an output which represents averaging over a number of samples which is substantially greater than L1. For example, the output may be equivalent to what would be obtained from a single filter summing the latest Ng samples.

## BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of an OFDM receiver in accordance with the present invention;

Figure 2 schematically represents an OFDM signal;

Figure 3 is a block diagram of a prior art arrangement for generating a synchronisation pulse;

Figure 4 schematically represents the effects of multi-path interference on the cross-correlation output;

Figure 5 is a block diagram of a synchronisation circuit of the present invention;

Figure 6 is a block diagram of a timing recovery circuit forming part of the synchronisation circuit;

Figure 7 represents part of a typical waveform derived from the correlation output, this part occupying a sub-interval within which a synchronisation pulse can be optimally generated; and

Figure 8 represents how the three values of Ns, L1 and L2 may vary.

## BEST MODE FOR CARRYING OUT THE INVENTION

Referring to Figure 1, an OFDM receiver 2 comprises an antenna 4 which receives a signal and presents it to a down-converter 6 which converts the RF signal to an IF signal. This is then converted into a baseband signal by an IF-to-baseband converter 8. This produces at its output complex samples of each transmitted OFDM symbol. These complex samples are digitised by an analog-to-digital (A/D) converter 10, and delivered via a fine frequency adjustment circuit 12 to a Fast Fourier Transform (FFT) circuit 14. The FFT circuit 14 converts the samples from the time domain to the frequency domain, and the symbol data at the output is provided to a phase rotator 15, a channel estimator and corrector 16 and a decoder 17.

The techniques of the present invention facilitate the provision of a feed-forward system, which doesn't rely on feedback or phase locked loops (PLL's) for adjusting the local oscillator frequencies. However, it would be possible in an alternative arrangement if desired to provide such feedback, so that the synchronisation circuit 18 would be responsive to, for example, the complex samples from the A/D converter 10 and and/or a signal from the channel estimator and corrector 16.

The complex samples are delivered to a symbol synchronisation circuit 20, which generates a frequency offset signal for the fine frequency adjustment circuit 12, and a synchronisation pulse for use by the Fast Fourier Transform (FFT) circuit 14. The FFT circuit 14 requires the synchronisation pulse so that each transformation operation is aligned with the start of the OFDM symbol.

The circuit described so far is known from the prior art, with the exception of the phase rotator 15. The present invention is directed, inter alia, to a novel and inventive technique for use in the symbol synchronisation circuit 20.

Referring to Figure 2(a), it is assumed that an OFDM symbol consists of Nu+Ng samples, representing Nu samples in the useful part U of the signal, preceded by Ng samples in the guard space G. The Ng samples in the guard space G contain the same data as the last Ng samples of the useful part U of the symbol (as indicated, in respect of one of the symbols, by hatching).

Referring to Figure 3, in a prior art synchronisation circuit, the complex samples from the IF-to-baseband converter 8 are provided in succession to a first-in first-out (FIFO) register 30 of a cross-correlator 28. This register contains Nu stages, so that it provides a corresponding delay of Nu samples. The output of the register 30 is provided to a complex conjugator circuit 32 of the correlator 28, which converts each sample into its complex conjugate. Then, at a multiplier 34 of the correlator 28, each complex conjugate is multiplied by an undelayed sample from the A/D

converter 10. (Alternatively, the complex conjugator 32 can be inserted into the other path to the multiplier 34.)

Whenever the complex conjugates of the delayed samples in the guard space G are multiplied by the samples of equal value derived from the end of the succeeding useful part U of the symbol, the correlator output will be high. At other times, the correlator output will adopt a random value. Figure 2(b) represents the output of the correlator. For clarity, Figure 2(b) represents an ideal output after averaging over a number of symbols, although in practice the averaging can occur at a later stage.

The output of the correlator 28 is provided to another FIFO register 36, this register containing Ng locations. An integrator 38 receives the output of the FIFO register 36 as well as, directly, the output of the correlator 28. The integrator serves to add each new sample to the current integrator output and subtract the sample received Ng samples earlier. Thus, the output represents the sum of the most recent Ng samples. The output is represented at Figure 2(c). It will be noted that this output gradually increases towards the end of each symbol, and then immediately starts decreasing. A peak detector (not shown) produces a timing signal whenever the integrator output reaches a peak (for example as shown at timing t in Figure 2). This is used as the synchronisation pulse for the FFT 14, and it will be noted that it will appear at the end of each symbol, i.e. exactly when the most recent Nu samples received in the FIFO register 36 are the appropriate ones for use by the FFT 14.

The FFT operates on the Nu samples of the useful part U of the signal. It will be appreciated from Figure 2 that the synchronisation signal t could be provided at any time within the last Ng samples of a symbol (i.e. whenever the Figure 2(b) waveform is at a high level), and still avoid ISI, because the provision of the guard space G means that the preceding Nu samples will be from the same signal.

Figure 4 shows one possible effect of multi-path interference. Figures 4(a) and 4(b) show the same signal, received at different times, Figure 4(a) representing the weaker of the signals, which in this case is received first.

Figure 4(c) represents the output which the correlator of Figure 3 would provide in the absence of the Figure 4(b) signal, and Figure 4(d) shows the output which the correlator would provide in the absence of the signal of Figure 4(a). With both signals present, the correlator produces an output represented at Figure 4(e). (Again, Figures 4(c) to 4(e) represent correlator outputs averaged over a plurality of symbols.)

The waveform in Figure 4(e) has three sections, 101, 102 and 103. These sections collectively represent an interval during which the correlator output is at a high-level due to significant correlation between values separated by Nu samples in one or both of the signals. The highest correlation, in sub-interval 102, occurs when positive correlations result from both signals. It will be noted that section 102 is the only part of the waveform in which the last Ng samples of a symbol from signal 4(a) occur at the same time as the last Ng samples of a

symbol of signal 4(b). Accordingly, sub-interval 2 is the only period in which a timing signal can be provided while avoiding ISI.

However, if the correlator output were to be integrated by the prior art circuit of Figure 3, the output would be represented by Figure 4(f). The peak of this output occurs at the end of section 3, which means that it would be too late. In particular, this means that although the FFT 14 would process only samples from symbol i of the Figure 4(b) signal, it would additionally process samples from symbol i+1 of the signal of Figure 4(a).

Referring to Figure 5, the synchronisation circuit 20 of the present embodiment of the invention comprises a correlator 28 formed by shift register 30, complex conjugator 32 and multiplier 34, as in the prior art arrangement of Figure 3. The output of the correlator 28 is delivered to an averager 46, which can also be an FIFO register as in the prior art arrangement of Figure 3, but in this case the number of stages is equal to L1, which is significantly less than Ng. The output of the FIFO 46 is delivered to a symbol averager 48, which sums each sample from FIFO 46 with the corresponding samples from the preceding Ns symbols. Accordingly, the output of the symbol averager is equal to the correlator output averaged over L1 samples and Ns symbols. In the case of multi-path interference as shown in Figure 4, the output will be similar to the waveform shown in Figure 4(e), with slight smoothing resulting from the L1 averaging.

This output is then delivered to a timing recovery circuit 50. This provides the synchronisation signal to the FFT 14.

The functions performed by the timing recovery circuit 50 are illustrated schematically by the blocks in Figure 6. The output samples from the symbol averager 48 are delivered to an absolute value circuit 52. This calculates the absolute value for each sample, i.e. $\sqrt{(x^2 + y^2)}$, where x and y are the in-phase and quadrature components of the sample. These are checked in a peak detector 54 which determines the value of the sample with the largest magnitude. A window generating circuit 56 responds to the samples from the absolute value circuit 52 and the peak value detected by the circuit 54 to determine the nearest samples on either side of the peak that are below a threshold which is equal to 0.75 times the peak value. The window generator 56 will therefore detect a range of samples, from $n_{min}$ to $n_{max}$ which represents the largest degree of correlation in the signal from the correlator. Figure 7 represents a typical waveform representing the samples from the symbol averager 48 during this period. Timing signals generated during the period $n_{min}$ to $n_{max}$ are likely to be suitable for avoiding ISI.

A synchronisation signal generator 58 generates a synchronisation pulse once per symbol, following an initialisation operation described below.

A comparator 60 compares the time at which this timing signal is generated with the range of sample values $n_{min}$ to $n_{max}$ determined by the window generator 56. If there is a significant difference, a value stored in a counter circuit 62 is altered. When one of several values stored in the counter circuit 62 reaches a predetermined threshold, a signal is sent to the signal generator 58 to adjust the timing of the synchronisation signal by an amount

which depends upon the range $n_{min}$ to $n_{max}$ calculated by the window generator 56. The arrangement is such that the timing signal will tend to be generated about midway between the samples $n_{min}$ and $n_{max}$, but that it will only be adjusted if there are persistent and/or significant errors in the current timing signal.

In this embodiment, the comparator 60 divides the range $n_{min}$ to $n_{max}$ into four quarters, q1, q2, q3 and q4, in order of increasing sample number, as shown in Figure 7. If the comparator 60 determines that the current timing of the synchronisation pulse lies in q1, then a first, "early" register in counter 62 is incremented by one. If the timing signal is found to lie in q4, then a second, "late" register is incremented by one. If the timing lies in q2 or q3, then both counters are decremented by one, although they are not allowed to go below zero. If at any time either counter reaches the value 4, then the counter circuit 62 causes the timing pulse generated by signal generator 58 to be shifted by an amount corresponding to $(n_{max} - n_{min})/4$ rounded to the nearest four samples, for the next symbol (or for a predetermined later symbol, for example the second or third succeeding symbol, to allow more time for the further processing described below). The timing pulse is moved forward or backwards depending upon whether it is the early or late counter which has reached the value 4.

A further register of counter circuit 62 is incremented or decremented depending on whether the timing lies outside the range $n_{min}$ to $n_{max}$. If this

occurs over four successive periods, the counter circuit 62 causes an initialisation operation.

This initialisation operation, which would occur when re-tuning to a new station or after power-on, results in the signal generator 58 being set to generate the timing signal at a position midway between $n_{min}$ and $n_{max}$. The initialisation operation also involves effecting changes to filter characteristics, as described below.

Whenever the signal generator 58 is caused to shift the timing of the synchronisation pulse, this will result in differential phase rotation of the carriers at the output of the FFT 14. To facilitate the handling of this, the counter circuit 62 of the timing recovery circuit 50 outputs a signal representing the amount of change applied to the synchronisation pulse, which signal is received by the phase rotator 15. The phase rotator 15 contains a look-up table storing pre-computed phase rotations corresponding to the possible values represented by the signal from the timing recovery circuit 50. Accordingly, upon receipt of this signal, the appropriate values are derived from the look-up table and the respective complex samples in the FFT output are adjusted by corresponding amounts. As an alternative, the phase rotator 15 can have means for computing the phase rotations in response to the signal from the timing recovery circuit 50. It will be noted that phase adjustment is facilitated because:

(a) the timing recovery circuit 50 produces a signal representative of the amount of adjustment of the synchronisation pulse;

(b) the timing recovery circuit is arranged, as described above, such that adjustments occur relatively infrequently;

(c) the amount of adjustment of the synchronisation pulse is rounded, which reduces the number of different possible adjustments applied to the timing of the synchronisation pulse;

(d) the timing recovery circuit is capable of specifying in advance the first symbol to be affected by the change in timing of the synchronisation pulse;

(e) because timing adjustment is performed only after the timing recovery circuit 50 has detected a succession of timing errors of a similar nature, it is possible if desired for the determination of appropriate phase rotations to be carried out in advance, for example when only one or two symbols have been determined to have timing errors, to allow even more time for the operation; and

(f) the changes to be applied can be pre-computed and stored in the look-up table.

Referring again to Figure 5, the output of the FIFO register 46 is also delivered to a further FIFO register 64, which acts as a sliding-window averager summing successive groups of L2 samples. The sampling rate is divided by L1, and the L2 most recent samples are summed. Preferably, L1 x L2 is substantially equal to Ng. The combination of these two averagers, 46 and 64, is functionally equivalent to the conventional averager 36 in the prior

art circuit of Figure 3. The output of the averager 64 is presented to a peak search circuit 66, which finds the sample with the largest magnitude and derives the angle of this sample, which provides an estimate of the fine frequency deviation. A signal representing this frequency offset is then provided to the frequency correction circuit 12 which corrects the frequency by phase rotation of the received samples.

In this embodiment, the L2 averager 66 averages successive values within a symbol, but alternatively the averaging could be performed over corresponding values in successive symbols (although this would delay the provision of an accurate fine frequency estimate).

Upon powering-up of the receiver, or when tuning to a new station, it is desirable to lock on to a new signal as soon as possible. This process preferably begins with the first received symbol. In this case, the value Ns, i.e. the number of symbols taken into account by the symbol averager 48, would start at 1, and would therefore increase for each newly-received symbol, although preferably the value would not be allowed to increase beyond a relatively small number (e.g. 8) so as to avoid too long a period, during which the signal may change, being taken into consideration.

Because Ns starts at a very low value and then increases, it is desirable to have the values L1 and L2 vary during this initial stage. L1 preferably starts at a relatively high value (although still preferably substantially smaller than Ng) because otherwise with low values of Ns the output of the L1 averager would be likely to be excessively erratic. Setting L1 equal to, for

example, 64 while Ns equals one would provide a good first timing estimate for the synchronisation signal from the first symbol. If L1 is initially set relatively high, then preferably L2 is set correspondingly low to compensate.

A table of Figure 8 represents an example of how these values may vary.

The values for the 9th and succeeding symbols remain at the values for the 8th symbol.

It will be appreciated that the present invention is effective not only in simple multi-path interference such as that described in connection with Figure 4, but also in other situations where signals are received via more than two paths. In these circumstances, the waveform of Figure 4(e) would be a more complex staircase waveform. However, so long as the spread of delay is such that there is a period in which all the guard spaces overlap, the techniques of the invention can be used to determine a corresponding window in which the synchronisation signal should be generated.

It is to be noted that, although reference has been made to the period in which there is overlap of the guard spaces, which are at the beginning of the symbols, as in the embodiment described above this is not necessarily the correct time to generate the synchronisation signal; in the embodiment above, there is a corresponding period, in the overlap of the duplicated data, when the signal should be issued. The choice of the appropriate interval will depend upon a number of factors, such as whether the guard space is considered to be at the beginning or the end of the signal, and whether (as in the above embodiment) the timing signal is used to define the end of a symbol period,

rather than the beginning. It is to be further noted that the description set out above disregards the delays which may occur, for example in the FIFO averager 46. In the embodiment described above, in practice, it is appropriate to make a correction corresponding to -(L1)/2 samples to account for this delay.

The above embodiment correlates samples spaced by Nu sample periods by means of multiplying one sample with the complex conjugate of the other sample. Other arrangements are possible. For example, the correlator could operate by taking the difference between the absolute values of samples separated by Nu sample periods, as described in our co-pending UK patent application no. BPA 9920446.3 (agent's reference J00041703 GB).

The invention has been described in the context of an OFDM receiver, in which the synchronisation pulse is used to define the window of samples on which a Fast Fourier Transformation is performed. However, the invention is also useful in other circumstances in which there is a need for a synchronisation pulse representing the symbol boundaries; for example, such a pulse would be valuable in a repeater where full FFT demodulation is not performed.

The functional elements described herein can be implemented either in dedicated hardware or in software.

## INDUSTRIAL APPLICABILITY

As has been described, the method of generating a synchronisation pulse representing a symbol boundary in an OFDM signal according to this invention comprising useful symbol periods separated by guard spaces, with data in each guard space corresponding to part of the data in a respective useful period, the method comprising a step of providing a signal representing the degree of correlation between samples of a received signal which are separated by a period corresponding to the useful part of the symbol, the signal thus providing an output representing for each symbol an interval during which significant correlation is found, and a step of determining a sub-interval within which a maximum degree of correlation occurs and arranging for the synchronisation pulse to be provided within this sub-interval. Therefore, the processing time including acquisition time can be shortened and the processing power can be decreased while still avoiding the inter-symbol-interference (ISI).

CLAIMS:

1. A method of generating a synchronisation pulse representing a symbol boundary in an OFDM signal comprising useful symbol periods separated by guard spaces, with data in each guard space corresponding to part of the data in a respective useful period, the method comprising providing a signal representing the degree of correlation between samples of a received signal which are separated by a period corresponding to the useful part of the symbol, the signal thus providing an output representing for each symbol an interval during which significant correlation is found, the method comprising the further step of determining a sub-interval within which a maximum degree of correlation occurs and arranging for the synchronisation pulse to be provided within this sub-interval.

2. A method as claimed in claim 1, wherein the sub-interval is determined by applying a threshold to the signal representing the degree of correlation.

3. A method as claimed in claim 2, wherein the threshold is varied.

4. A method as claimed in claim 3, wherein the threshold represents a value which is dependent upon the maximum value of the signal representing the degree of correlation.

5. A method as claimed in any preceding claim, in which the signal representing the degree of correlation is subject to filtering prior to using the signal to determine said sub-interval, the filtering being such that each filtered output sample represents, substantially, an average of a predetermined number of successive samples, said predetermined number being substantially less than the number of samples within a guard space.

6. A method as claimed in claim 5, in which the filtered output represents values averaged over a plurality of symbols.

7. A method as claimed in claim 6, in which the number of symbols over which the filtered output values are averaged increases during an acquisition stage, and in which the filtering is adjusted during that acquisition stage so as to decrease the number of successive samples, the average of which is represented by each filtered output sample.

8. A method as claimed in claim 5, 6 or 7, wherein the filtered output is subjected to further filtering before being processed to provide a signal representing a fine frequency offset.

9. A method as claimed in any preceding claim, including the step of adjusting the timing of the synchronisation pulse only if a calculated error in the current timing exceeds a predetermined threshold.

10. A method as claimed in any preceding claim, including the step of adjusting the timing of the synchronisation pulse only if the current timing is determined to be in error over a predetermined number of symbol periods, the predetermined number of symbol periods being greater than one.



11. A method as claimed in any preceding claim, wherein the timing of the synchronisation pulse is adjusted in predetermined quantities corresponding to a plurality of sample periods.

12. A method of generating a synchronisation pulse representing a symbol boundary in an OFDM signal comprising useful symbol periods separated by guard spaces, with data in each guard space corresponding to part of the data in a respective useful period, the method including the step of adjusting the timing of the synchronisation pulse in response to a calculated error in the current timing exceeding a predetermined threshold.

13. A method of generating a synchronisation pulse representing a symbol boundary in an OFDM signal comprising useful symbol periods separated by guard spaces, with data in each guard space corresponding to

part of the data in a respective useful period, the method including the step of adjusting the timing of the synchronisation pulse in response to the current timing being determined to be in error over a predetermined number of symbol periods, the predetermined number of symbol periods being greater than one.

14. A method as claimed in claim 13, wherein the timing of the synchronisation pulse is adjusted in response to the current timing having an error exceeding a predetermined threshold over said predetermined number of symbol periods.

15. A method of generating a synchronisation pulse representing a symbol boundary in an OFDM signal comprising useful symbol periods separated by guard spaces, with data in each guard space corresponding to part of the data in a respective useful period, the method including the step of adjusting the timing of the synchronisation pulse in predetermined quantities corresponding to a plurality of sample periods.

16. A method as claimed in any one of claims 12 to 14, wherein the timing of the synchronisation pulse is adjusted in predetermined quantities corresponding to a plurality of sample periods.

17. A method of receiving an OFDM signal, the method including the step of generating a synchronisation pulse using a method as claimed in any preceding claim, and using the synchronisation pulse in order to apply a Fast Fourier Transform to complex samples derived from the OFDM signal.

18. A method according to claim 17, the method further including the step of providing, when the timing of the synchronisation pulse is altered, a signal representing the degree of alteration, and applying to the transformed samples phase rotations determined by this signal.

19. A method as claimed in claim 18, wherein the phase rotations are determined by values in a look-up table addressed in accordance with the signal representing the degree of alteration of the synchronisation pulse timing.

20. A method of receiving an OFDM signal, the method including the steps of generating a synchronisation pulse and using the synchronisation pulse in order to apply Fast Fourier Transform to complex samples derived from the OFDM signal, the method further including the step of providing, when the timing of the synchronisation pulse is altered, a signal representing the degree of alteration, and applying to the transformed samples phase rotations determined by this signal.

21. A method as claimed in claim 20, wherein the phase rotations are determined by values in a look-up table addressed in accordance with the signal representing the degree of alteration of the synchronisation pulse timing.

22. Apparatus for generating a synchronising pulse, the apparatus operating according to a method as claimed in any one of claims 1 to 16.

23. An OFDM receiver arranged to operate in accordance with a method according to any one of claims 17 to 21.

# ABSTRACT

In an OFDM receiver, a synchronisation pulse for defining a Fast Fourier Transform window is generated by examining the output of a correlator to find a sub-interval within which there is maximum correlation between samples of the symbol separated by the length of the useful part of the symbol. The synchronisation pulse is generated during this sub-interval(102). Adjustments to the timing of the synchronisation pulse are made only if the current error is significant and persistent. A signal representing the amount of adjustment is used to determine phase rotations applied to the output of the FFT circuit.

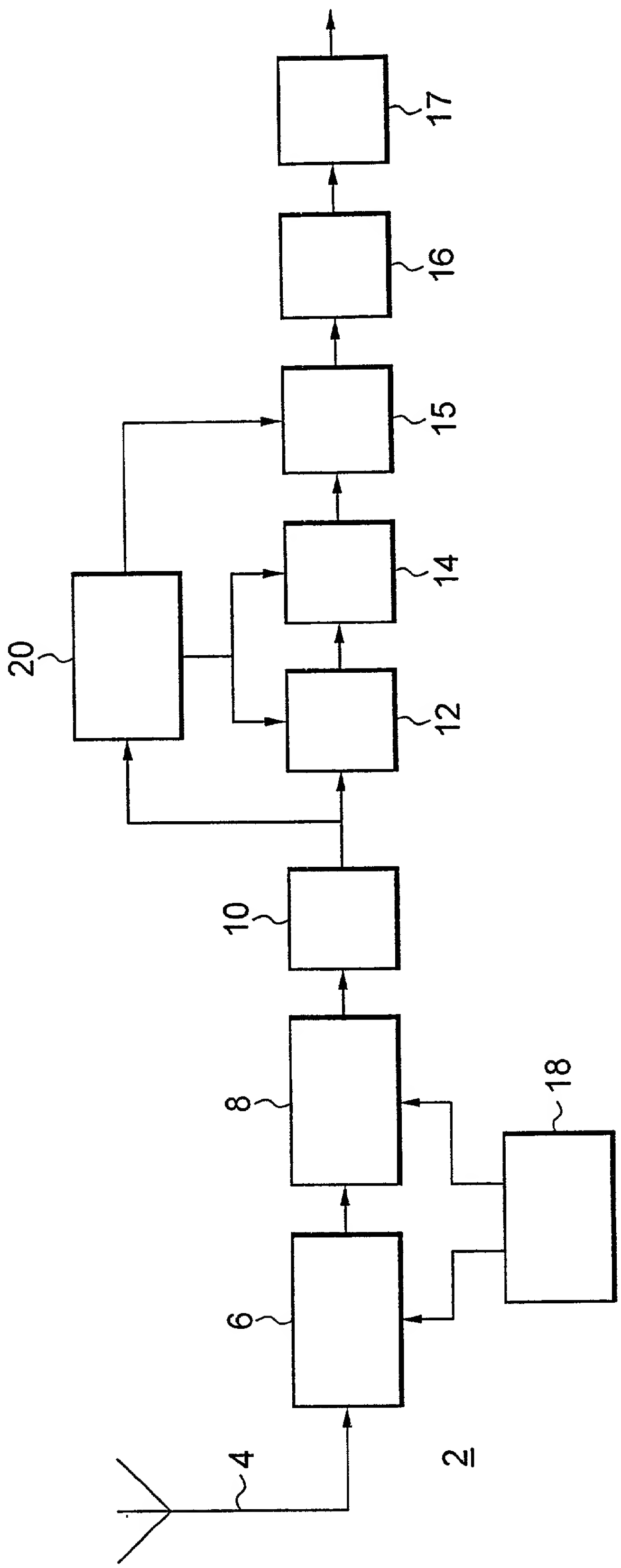


FIG.1

FIG.2

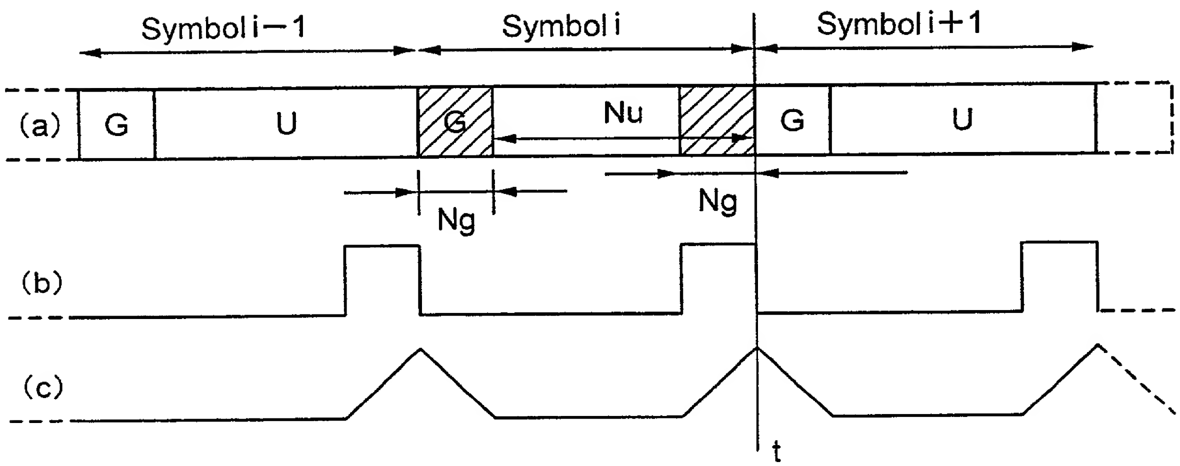

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FIG.3

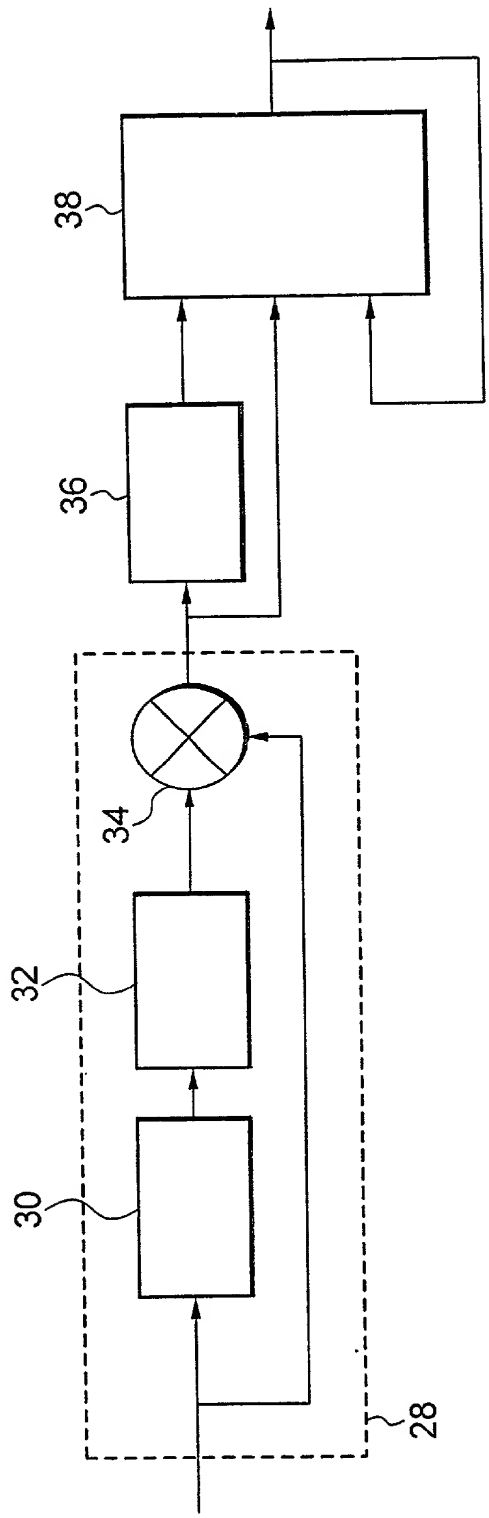
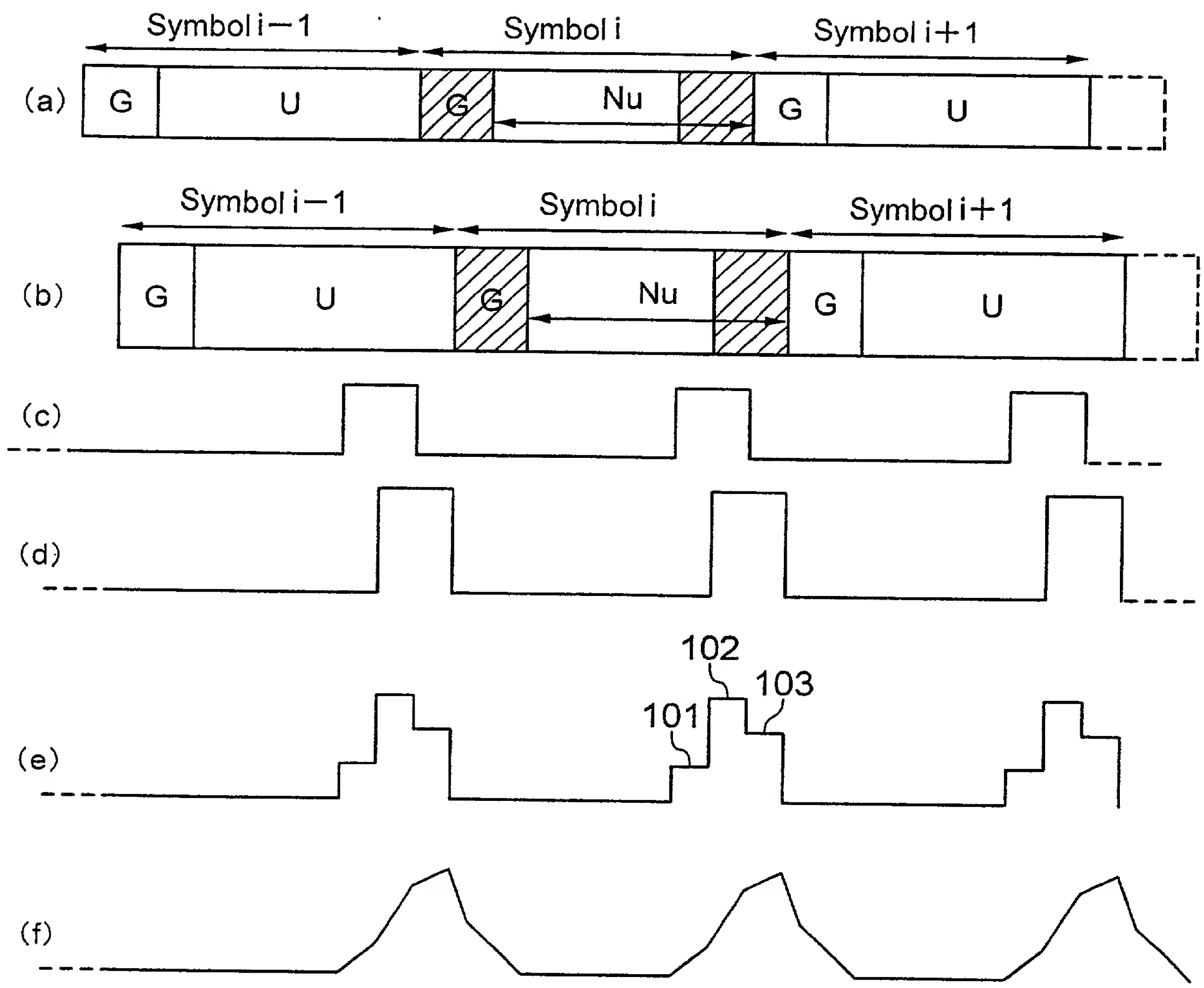


FIG.4


Symbol i−1
Symbol i
Symbol i+1
(a)
G
U
G
Nu
G
U
(b)
G
U
G
Nu
G
U
(c)
(d)
(e)
101
102
103
(f)

09/807959

FIG.5

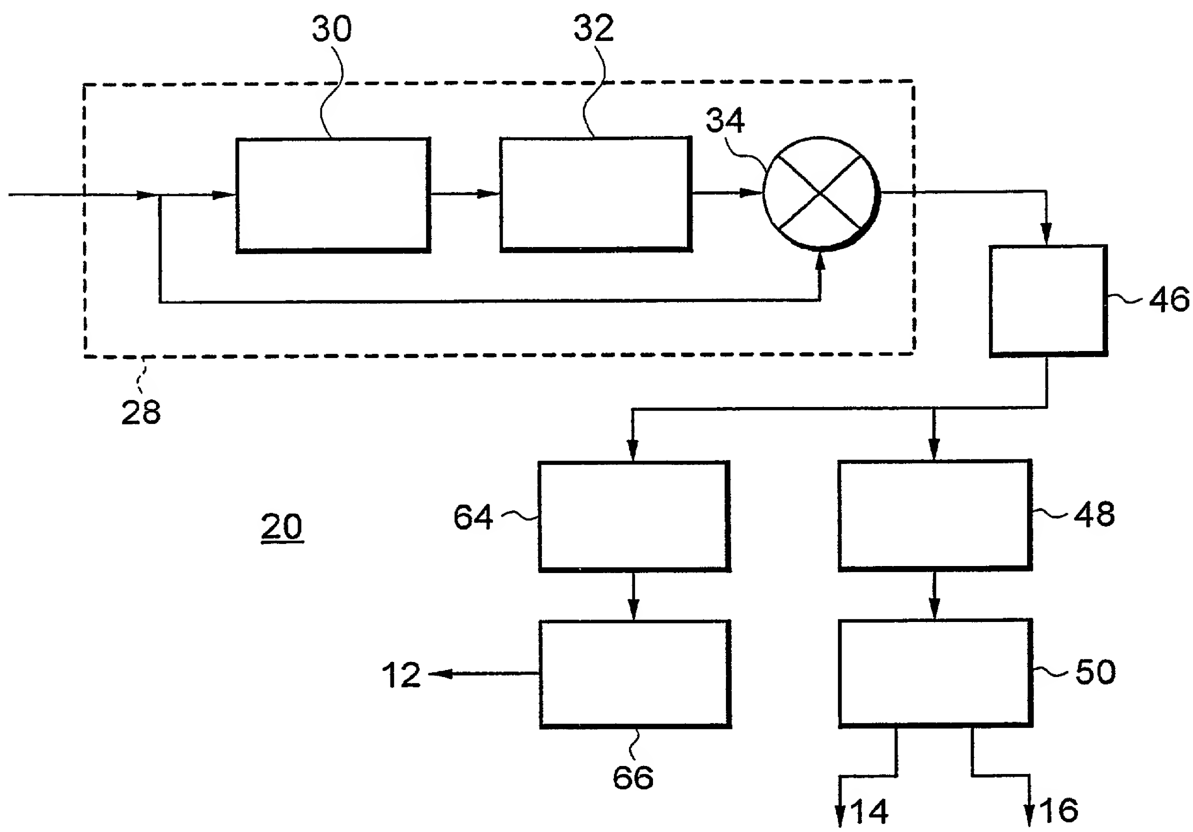



FIG.6

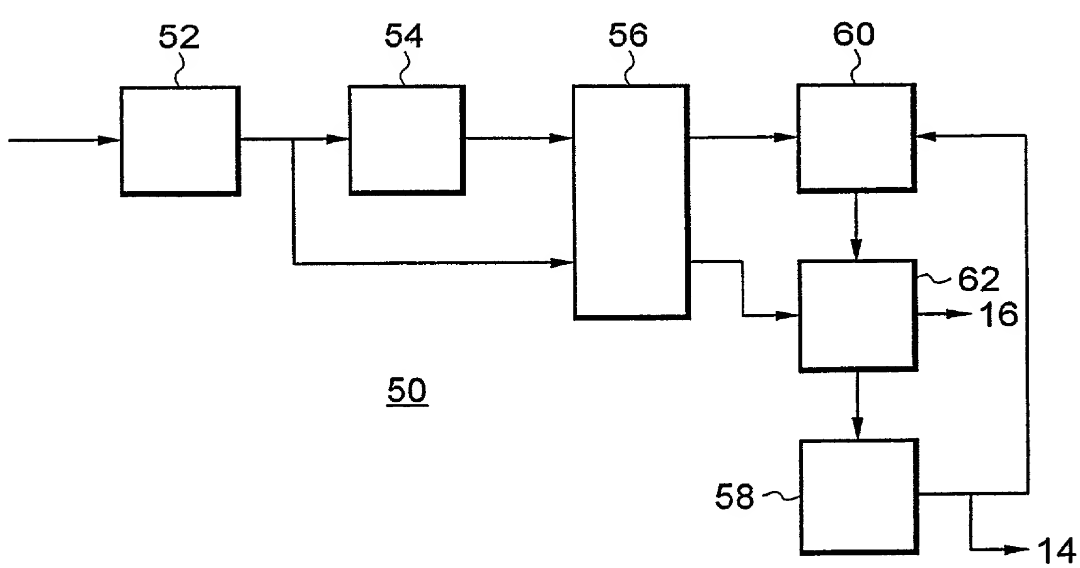


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FIG.7

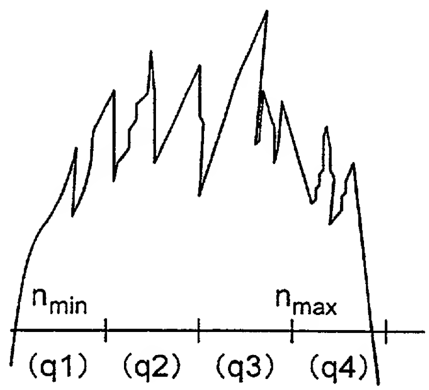


FIG.8

| $N_S$ | L1 | L2 |
|---|---|---|
| 1 | 64 | 4 |
| 2 | 32 | 8 |
| 3 | 21 | 12 |
| 4 | 16 | 16 |
| 5 | 13 | 20 |
| 6 | 11 | 24 |
| 7 | 9 | 28 |
| 8 | 8 | 32 |

# Declaration and Power of Attorney For Patent Application

# 特許出願宣言書及び委任状

## Japanese Language Declaration

## 日本語宣言書

下記の氏名の発明者として、私は以下の通り宣言します。

私の住所、私書箱、国籍は下記の私の氏名の後に記載された通りです。

下記の名称の発明に関して請求範囲に記載され、特許出願している発明内容について、私が最初かつ唯一の発明者（下記の氏名が一つの場合）もしくは最初かつ共同発明者（下記の名称が複数の場合）であると信じています。

上記発明の明細書は、

☐ 本書に添付されています。

☐ __月__日に提出され、米国出願番号または特許協定条約国際出願番号を______とし、（該当する場合）______に訂正されました。

私は、特許請求範囲を含む上記訂正後の明細書を検討し、内容を理解していることをここに表明します。

私は、連邦規則法典第37編第1条56項に定義されるとおり、特許資格の有無について重要な情報を開示する義務があることを認めます。

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled.

METHOD OF GENERATING A SYNCHRONISATION PULSE AND METHOD OF RECEIVING AN OFDM SIGNAL

the specification of which

☐ is attached hereto.

☒ was filed on August 24, 2000 as United States Application Number or PCT International Application Number PCT/JP00/05704 and was amended on ______ (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56.

# Japanese Language Declaration
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私は、米国法典第35編119条 (a) - (d) 項又は365条 (b) 項に基づき下記の、米国以外の国の少なくとも一ヵ国を指定している特許協力条約365 (a) 項に基づく国際出願、又は外国での特許出願もしくは発明者証の出願についての外国優先権をここに主張するとともに、優先権を主張している、本出願の前に出願された特許または発明者証の外国出願を以下に、枠内をマークすることで、示しています。

I hereby claim foreign priority under Title 35, United States Code, Section 119 (a)-(d) or 365(b) of any foreign application(s) for patent or inventor's certificate, or Section 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT International application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application(s)
外国での先行出願

| (Number) (番号) | (Country) (国名) | (Day/Month/Year Filed) (出願年月日) | Priority Claimed 優先権主張 | |
|---|---|---|---|---|
| 9920447.1 | Great Britain | 27 / 08 / 1999 | ☒ Yes はい | ☐ No いいえ |
| | | | ☐ Yes はい | ☐ No いいえ |

私は、第35編米国法典119条 (e) 項に基づいて下記の米国特許出願規定に記載された権利をここに主張いたします。

I hereby claim the benefit under Title 35, United States Code, Section 119(e) of any United States provisional application(s) listed below.

| (Application No.) (出願番号) | (Filing Date) (出願日) |
|---|---|
| | |
| | |

私は、下記の米国法典第35編120条に基づいて下記の米国特許出願に記載された権利、又は米国を指定している特許協力条約365条 (c) に基づく権利をここに主張します。また、本出願の各請求範囲の内容が米国法典第35編112条第1項又は特許協力条約で規定された方法で先行する米国特許出願に開示されていない限り、その先行米国出願書提出日以降で本出願書の日本国内または特許協力条約国際提出日までの期間中に入手された、連邦規則法典第37編1条56項で定義された特許資格の有無に関する重要な情報について開示義務があることを認識しています。

I hereby claim the benefit under Title 35, United States Code, Section 120 of any United States application(s), or Section 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of Title 35, United States Code Section 112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of application.

| (Application No.) (出願番号) | (Filing Date) (出願日) | (Status: Patented, Pending, Abandoned) (現況：特許許可済、係属中、放棄済) |
|---|---|---|
| | | |
| | | |

私は、私自信の知識に基づいて本宣言書中で私が行なう表明が真実であり、かつ私の入手した情報と私の信じるところに基づく表明が全て真実であると信じていること、さらに故意になされた虚偽の表明及びそれと同等の行為は米国法典第18編第1001条に基づき、罰金または拘禁、もしくはその両方により処罰されること、そしてそのような故意による虚偽の声明を行なえば、出願した、又は既に許可された特許の有効性が失われることを認識し、よってここに上記のごとく宣誓を致します。

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

# Japanese Language Declaration
# (日本語宣言書)

委任状：私は下記の発明者として、本出願に関する一切の手続きを米特許商標局に対して遂行する弁理士または代理人として、下記の者を指名いたします。
(弁護士、または代理人の指名及び登録番号を明記のこと)

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith: *(list name and registration number)*

28

Norman F. Oblon, Reg. No. 24,618; Marvin J. Spivak, Reg. No. 24,913; C. Irvin McClelland, Reg. No. 21,124; Gregory J. Maier, Reg. No. 25,599; Arthur I. Neustadt, Reg. No. 24,854; Richard D. Kelly, Reg. No. 27,757; James D. Hamilton, Reg. No. 28,421; Eckhard H. Kuesters, Reg. No. 28,870; Robert T. Pous, Reg. No. 29,099; Charles L. Gholz, Reg. No. 26,395; William E. Beaumont, Reg. No. 30,996; Jean-Paul Lavalleye, Reg. No. 31,451; Stephen G. Baxter, Reg. No. 32,884; Richard L. Treanor, Reg. No. 36,379; Steven P. Weihrouch, Reg. No. 32,829; John T. Goolkasian, Reg. No. 26,142; Richard L. Chinn, Reg. No. 34,305; Steven E. Lipman, Reg. No. 30,011; Carl E. Schlier, Reg. No. 34,426; James J. Kulbaski, Reg. No. 34,648; Richard A. Neifeld, Reg. No. 35,299; J. Derek Mason, Reg. No. 35,270; Surinder Sachar, Reg. No. 34,423; Jeffrey B. McIntyre, Reg. No. 36,867; William T. Enos, Reg. No. 33,128; Michael E. McCabe, Jr., Reg. No. 37,182; Bradley D. Lytle, Reg. No. 40,073; and Michael R. Casey, Reg. No. 40,294, with full powers of substitution and revocation.

書類送付先

Send Correspondence to:

OBLON, SPIVAK, McCLELLAND, MAIER & NEUSTAD[redacted]
FOURTH FLOOR
1755 JEFFERSON DAVIS HIGHWAY
ARLINGTON, VIRGINIA 22202 U.S.A.

直接電話連絡先：（名前及び電話番号）

Direct Telephone Calls to: (name and telephone number)

(703) 413-3000

| | |
|---|---|
| 単独発明者または第一の共同発明者の氏名 | Full name of sole or first joint inventor<br>Stephen K. BARTON |
| 発明者の署名　日付 | Inventor's signature　SKBarton　Date 10/5/01 |
| 住所 | Residence<br>Surrey, U.K.　UKX |
| 国籍 | Citizenship<br>U.K. |
| 郵便の宛先 | Post Office Address<br>18-20 Frederick Sanger Road, |
| | The Surrey Research Park, Guildford,<br>Surrey GU2 6YD U.K. |
| 第二の共同発明者の氏名 | Full name of second joint inventor, if any<br>Stephen M. BRUNT |
| 第二の共同発明者の署名　日付 | Second joint Inventor's signature　Date 27/5/01 |
| 住所 | Residence<br>Surrey, U.K.　UKX |
| 国籍 | Citizenship<br>U.K. |
| 郵便の宛先 | Post Office Address<br>18-20 Frederick Sanger Road, |
| | The Surrey Research Park, Guildford,<br>Surrey GU2 6YD U.K. |

(第三以降の共同発明者についても同様に記載し、署名すること)

(Supply similar information and signature for third and subsequent joint inventors.)

# Japanese Language Declaration
（日本語宣言書）

3-の

| | |
|---|---|
| 第三の共同発明者の氏名 | Full name of third joint inventor, if any<br>Javier ECHAVARRI |
| 第三の共同発明者の署名　日付 | Third joint Inventor's signature　Date |
| 住所 [redacted] | Residence<br>Surrey, U.K. UKX |
| 国籍 | Citizenship<br>Spain |
| 郵便の宛先 | Post Office Address<br>18-20 Frederick Sanger Road, |
| | The Surrey Research Park, Guildford,<br>Surrey GU2 6YD U.K. |

4-の

| | |
|---|---|
| 第四の共同発明者の氏名 | Full name of fourth joint inventor, if any<br>John ORRISS |
| 第四の共同発明者の署名　日付 | Fourth joint Inventor's signature　Date<br>10 May 01 |
| 住所 | Residence<br>Surrey, U.K. UKX |
| 国籍 | Citizenship<br>U.K. |
| 郵便の宛先 | Post Office Address<br>18-20 Frederick Sanger Road, |
| | The Surrey Research Park, Guildford,<br>Surrey GU2 6YD U.K. |

| | |
|---|---|
| 第五の共同発明者の氏名 | Full name of fifth joint inventor, if any |
| 第五の共同発明者の署名　日付 | Fifth joint Inventor's signature　Date |
| 住所 | Residence |
| 国籍 | Citizenship |
| 郵便の宛先 | Post Office Address |
| | |

| | |
|---|---|
| 第六の共同発明者の氏名 | Full name of sixth joint inventor, if any |
| 第六の共同発明者の署名　日付 | Sixth joint Inventor's signature　Date |
| 住所 | Residence |
| 国籍 | Citizenship |
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（第六またはそれ以降の共同発明者に対しても同様な情報および署名を提供すること。）

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